

Fostering a Collaboration Ecosystem to Drive Directed Self- Assembly Development

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TOKYO ELECTRON



What is a Collaboration Ecosystem?

How do people “live” in a small town? = Torrey, Utah (pop 182)

Everyone works together (collaboration) to live in a beautiful mountainous city (ecosystem) → achieves a common goal



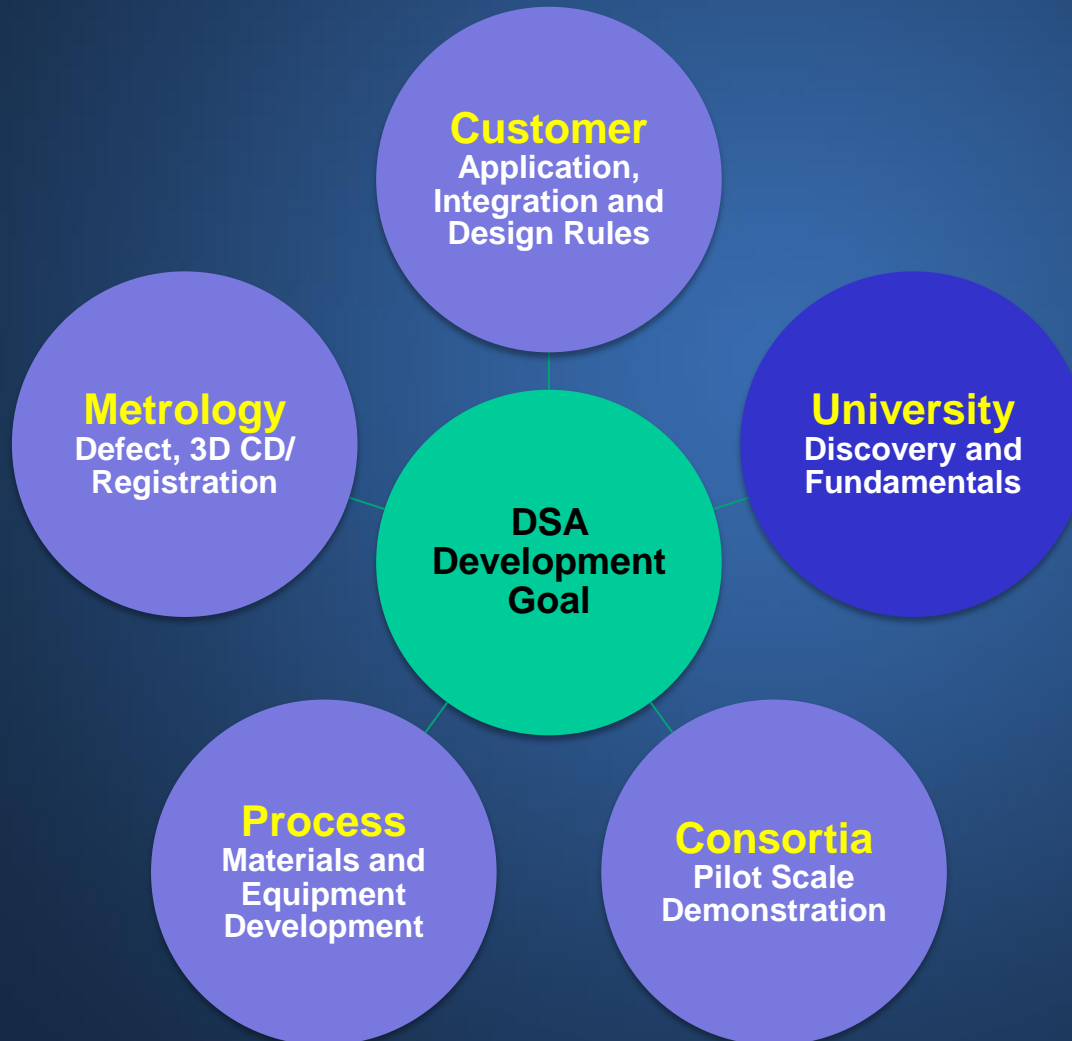
DSA Collaboration Ecosystem

DSA Common Goal: Develop economically viable patterning solutions



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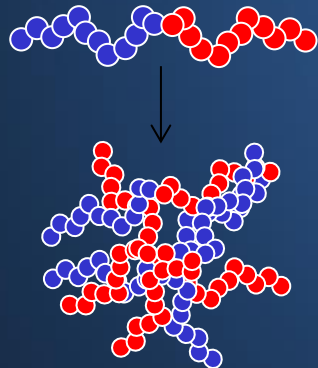


Directed Self-Assembly (DSA)

Disordered state

Two different
property polymers
are connected with
covalent bond

Polymer A Polymer B

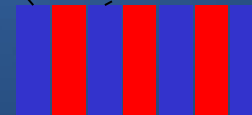
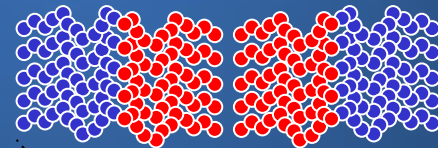


Coat
& Bake



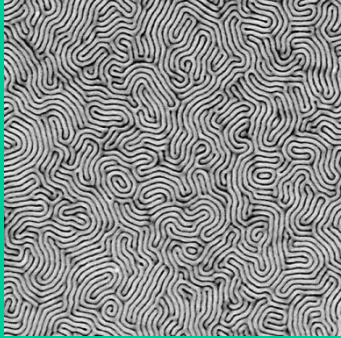
Ordered State

A with A and B with B
approach each other
A and B are
separated



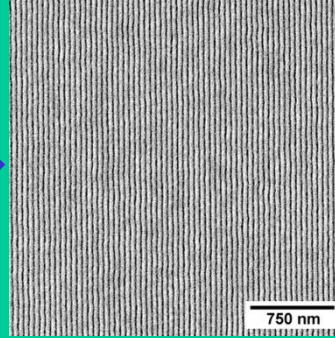
University DSA Demonstrations

**P(S-b-MMA) on
Unpatterned Surface**



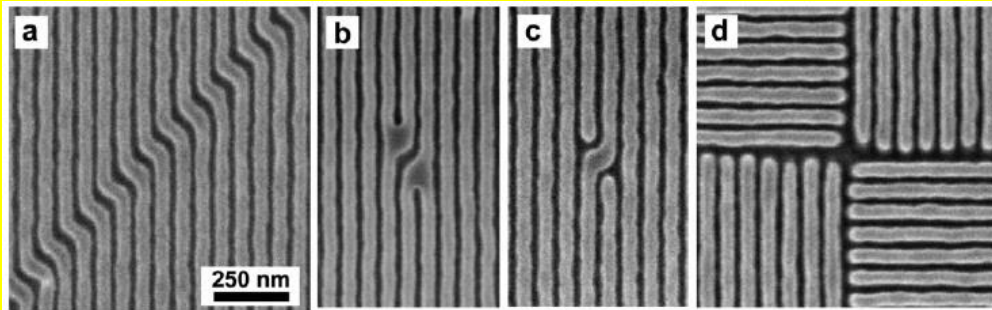
Directed

**P(S-b-MMA) on
Patterned Surface**



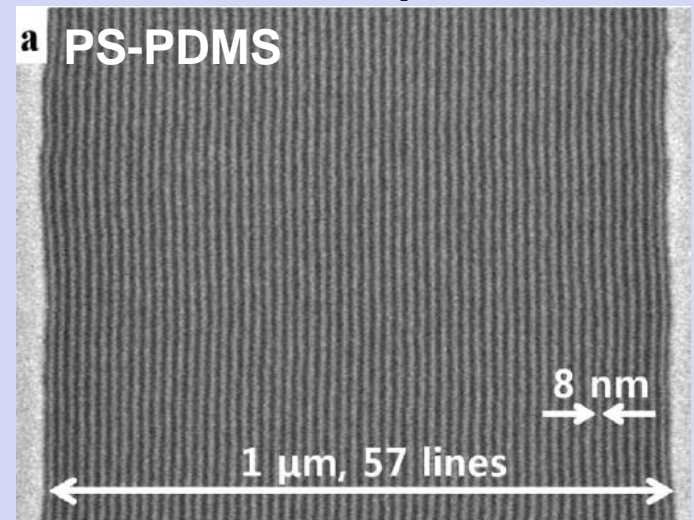
S. O. Kim, H. H. Solak, M. P. Stoykovich, N. J. Ferrier, J. J. de Pablo, P. F. Nealey, *Nature*, 2003, 424, 411.

Applicability



M. P. Stoykovich, H. Kang, K. C. Daoulas, G. Liu, C. C. Liu, J. J. de Pablo, M. Muller, P. F. Nealey, *ACS Nano*, 1 (3), 168 (2007)

Small size pattern



Y. S. Jung, J.B. Chang, E. Verploegen, K. K. Berggren, C. A. Ross, *Nano Lett*, 10, 1000 (2010)

DSA Collaboration Ecosystem

DSA Common Goal: Develop economically viable patterning solutions



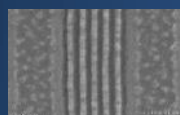
L/S Demonstrations (2012)



PS-*b*-PMMA Grapho-Epitaxy



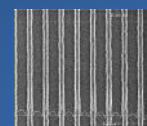
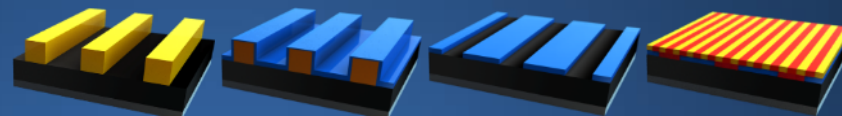
14 nm HP DSA pattern



RIE Etch



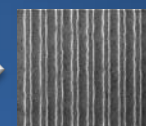
PS-PMMA Chemo-Epitaxy (Lift off)



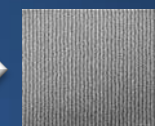
DSA Pre-pattern
~35 nm LN/ 112 nm pitch



Neutral Layer
Coat



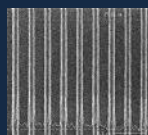
Develop
Liftoff



After 4x DSA anneal
14 nm line/spaces



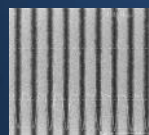
Etch Guide Chemo-Epitaxy



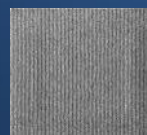
DSA Pre-pattern
~35 nm LN/ 100 nm pitch



Trim etch
~15 nm



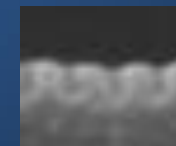
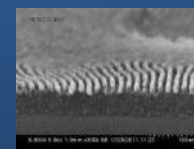
Wet resist
strip



After 4x DSA process
12.5 nm line/spaces



High Chi L/S Demonstration



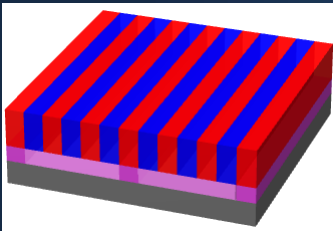
9 nm HP

B. Rath sack, et. al., "Pattern Scaling with Directed Self Assembly Through Lithography and Etch Process Integration", SPIE 8323-10 (2012)

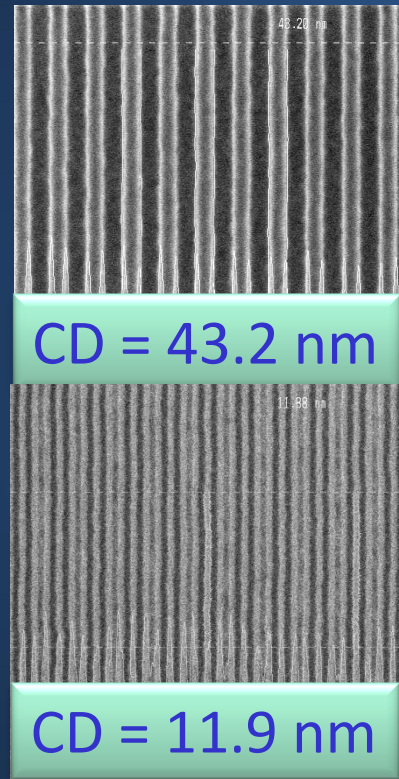
L/S CD Self Healing (2012)

Guide pitch
 $L_s = 84 \text{ nm}$

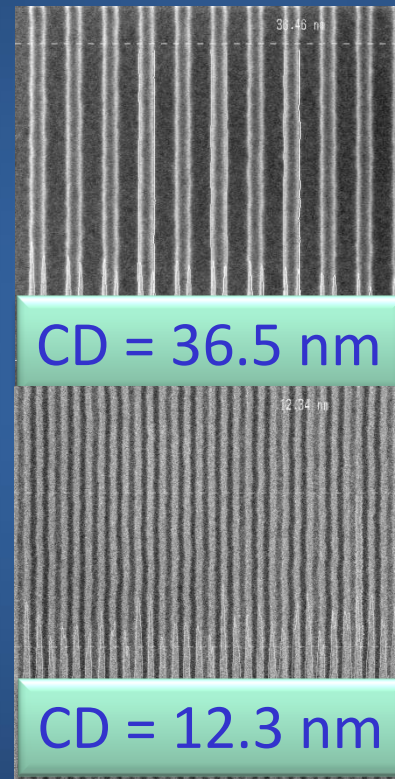
DSA pitch
 $L_0 = 28 \text{ nm}$



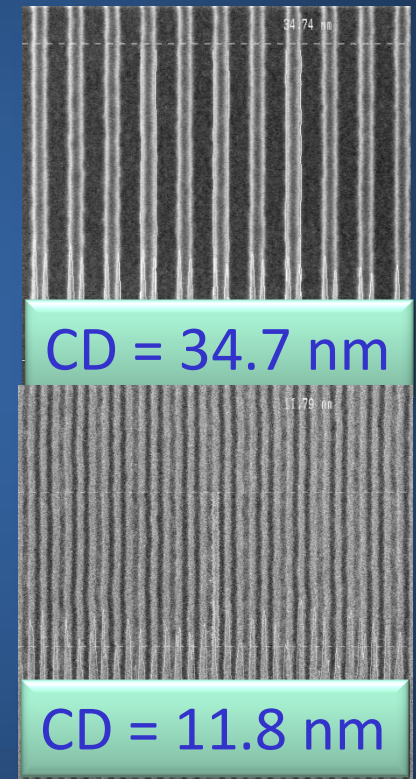
19 mJ/cm²



22 mJ/cm²



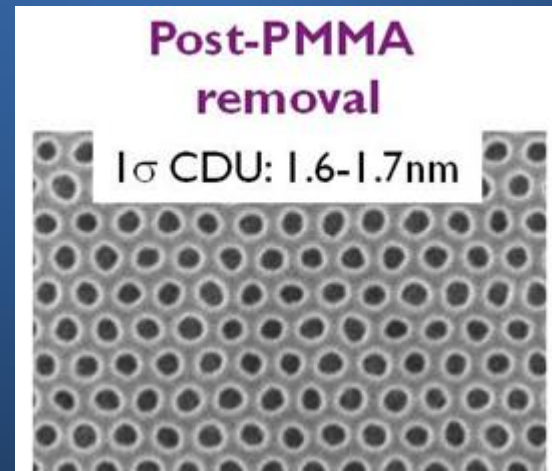
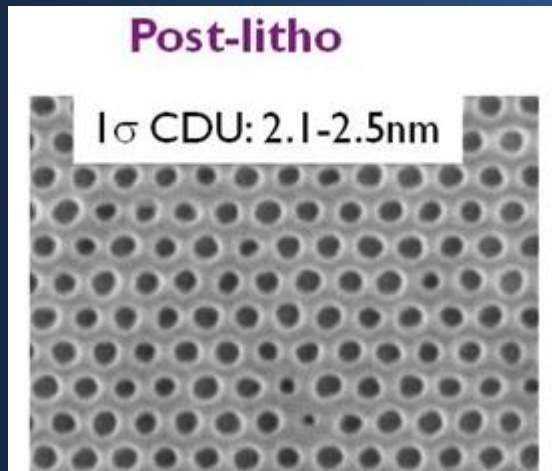
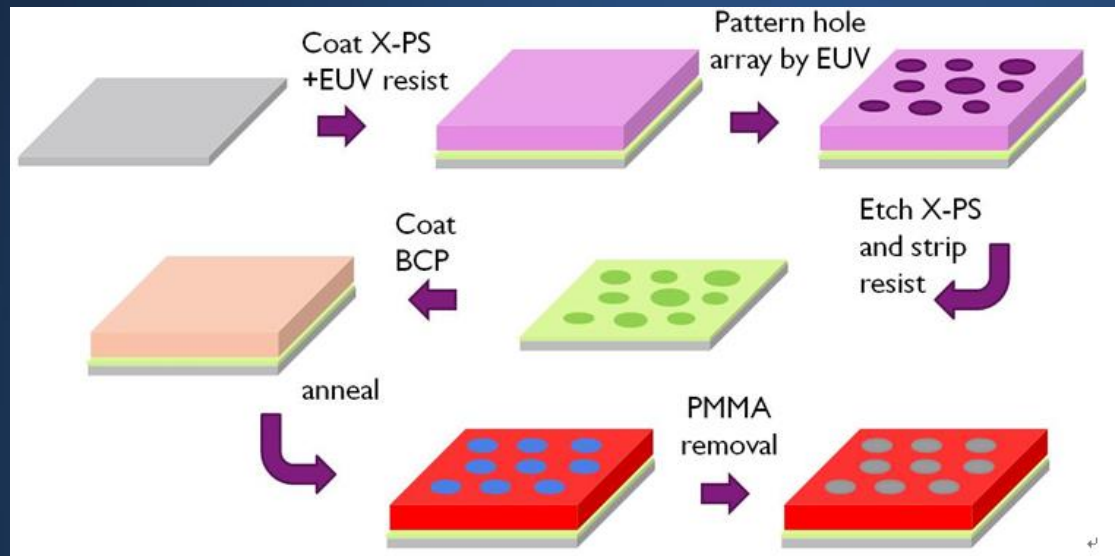
27 mJ/cm²



P. Rincon, et. al., "All-track directed self assembly of block copolymers," SPIE 8323-12 (2012)

EUV Hole Pattern CD Healing (2013)

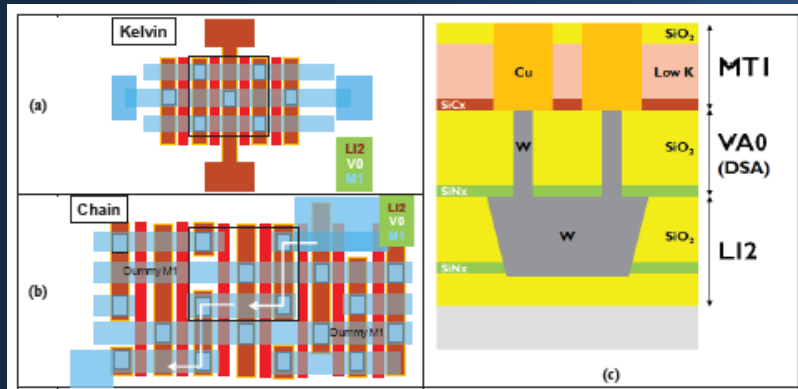
P = 54 nm
EUV exposure



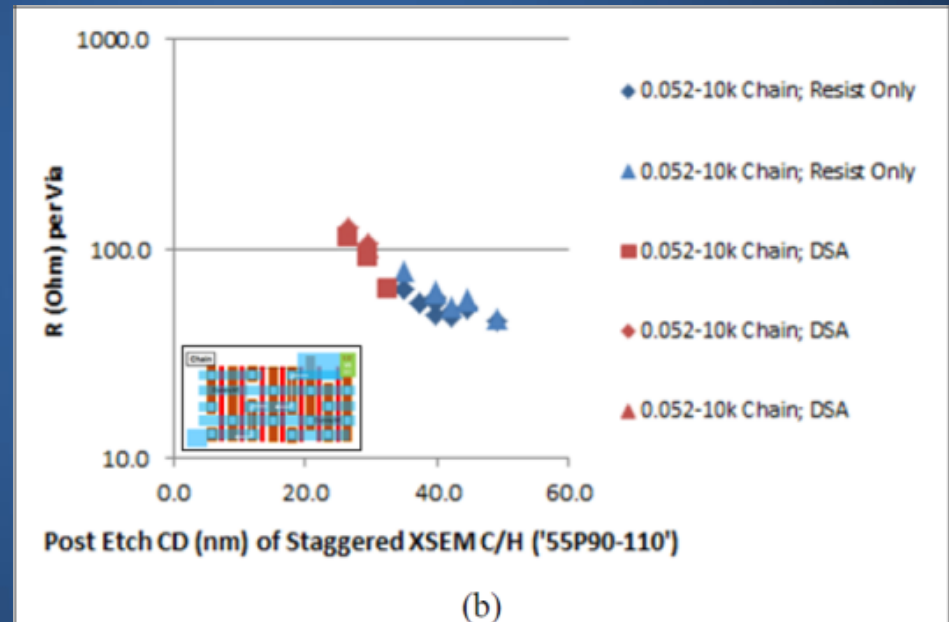
R. Gronheid, et. al., "Rectification of EUV-patterned contact holes using directed self assembly," SPIE 8679-10 (2013)

DSA Hole Shrink Electrical Testing (2013)

IMEC Via Chain Structures



Via Chain Electrical Resistance Data



DSA Hole Shrink Development

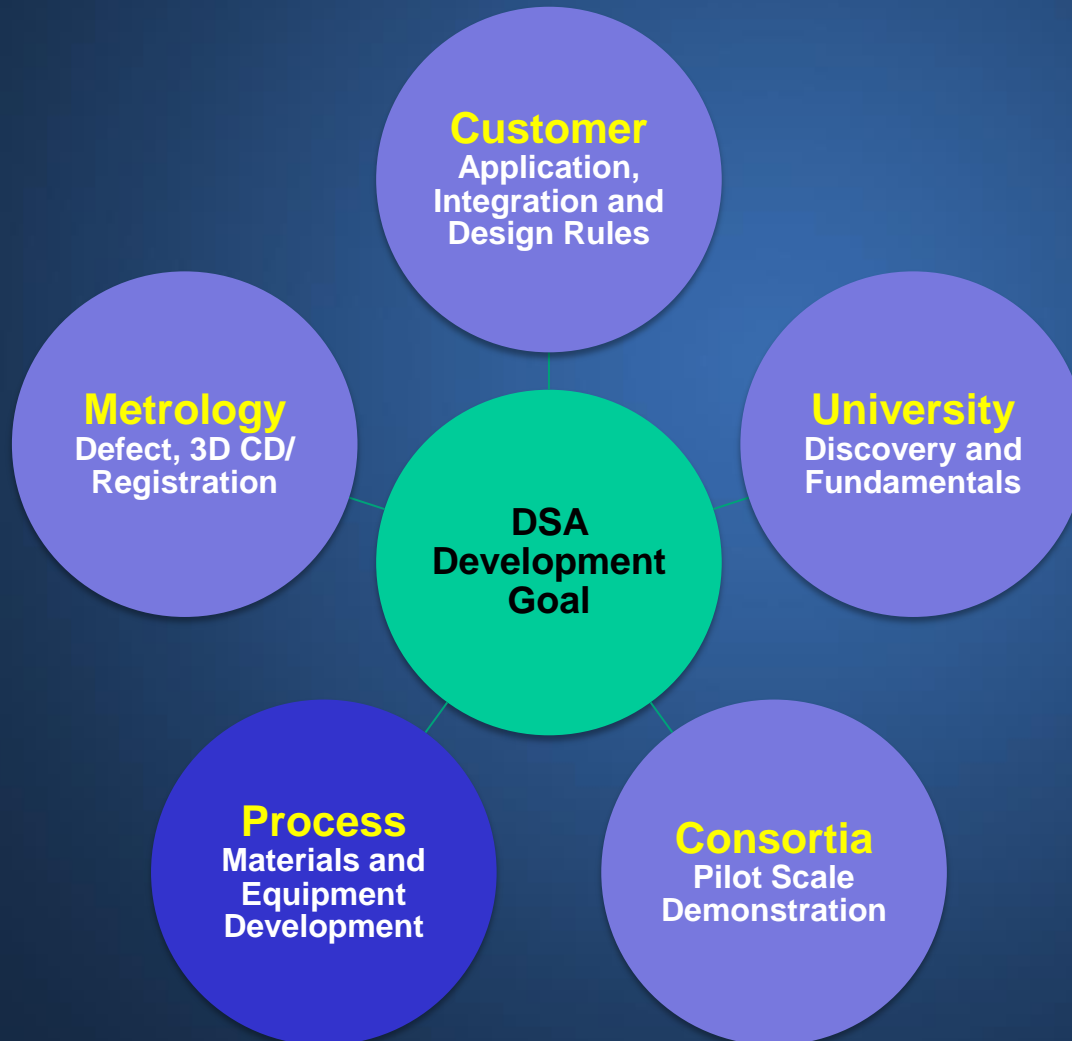
Step	1	2	3	4	5	6
Description	Litho	DSA Shrink	HM Etch	ILD Etch	SiN ₂ Etch	APF Strip
Integ. Cartoon						
Image XSEM STG P90-110						
CD (nm)	56.9	35.9	30.5	27.5	31.8	28.4
3σSiDev (nm)	1.9	3.5	2.6	1.6	1.5	1.2
CD Range (nm)	3.4	4.7	6.8	3.1	2.3	2.3
Delta (nm)	--	-21 (-37%)	-5.4 (-15%)	-3.0 (-10%)	+4.3 (+16%)	-5.4 (-17%)

T. Younkin, et. Al., "Progress in Directed Self-Assembly Hole Shrink Applications," SPIE 8680-20 (2013)



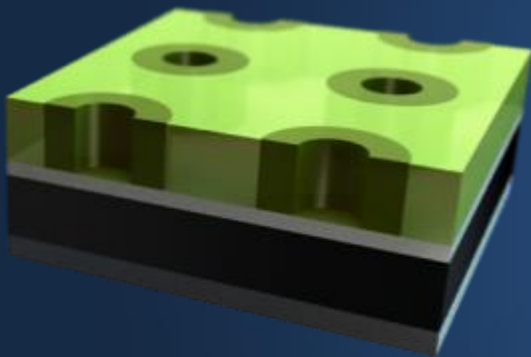
DSA Collaboration Ecosystem

DSA Common Goal: Develop economically viable patterning solutions

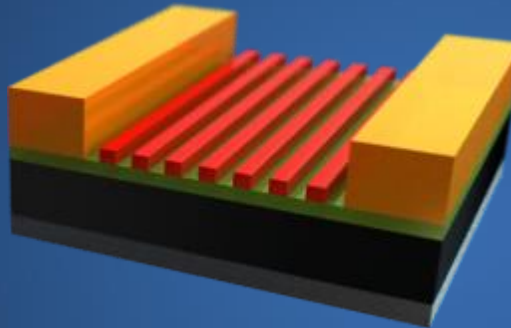


Complementary Lithography

**Self-Aligned Hole
or Pitch Shrink**



**Line/ Space Pitch
Shrink**



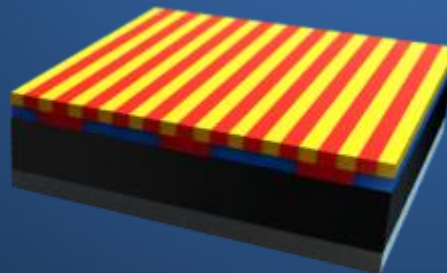
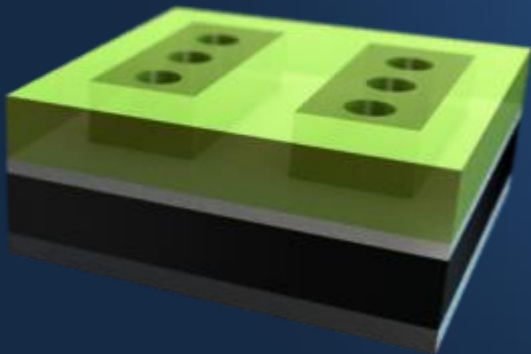
Novel capability

Resolution

CDU/ LWR
Healing

Line Pattern
Collapse Prevention

Process Window
Improvement
(Dose, Focus)

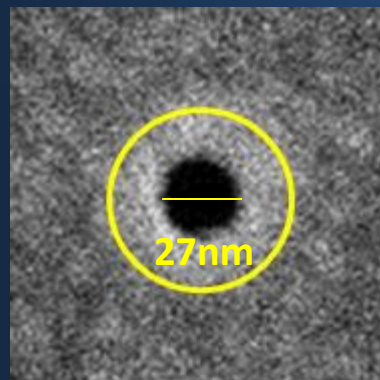
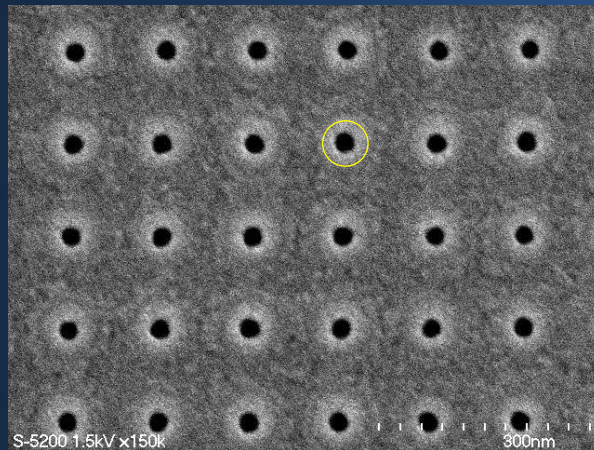


Materials and Surface Treatments

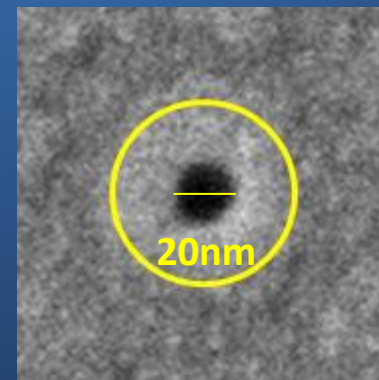
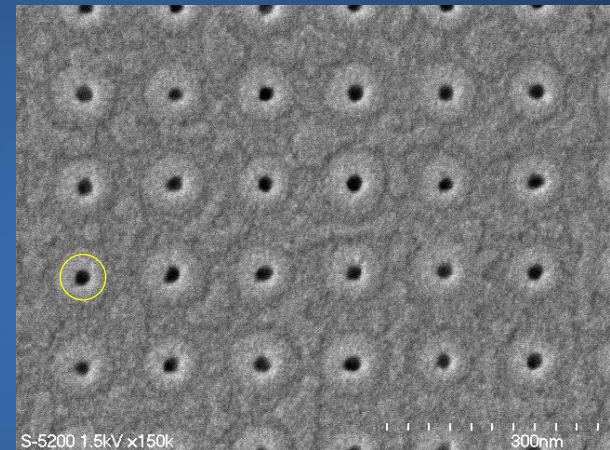
Initial Guide Hole CD : 65nm

PS-b-PMMA, L0=54nm

PS Wet Wall

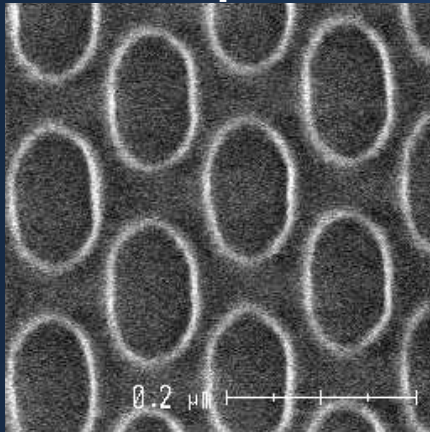


PMMA Wet Wall

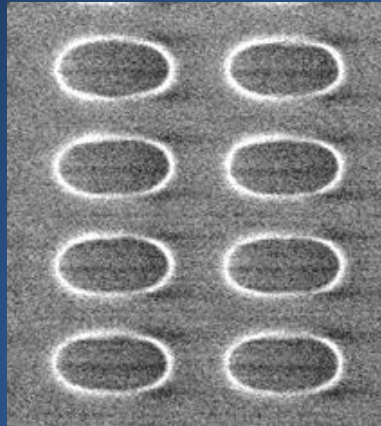


Graphoepitaxy Hole Applications

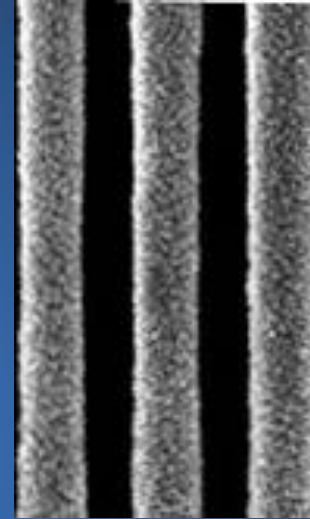
Ellipse



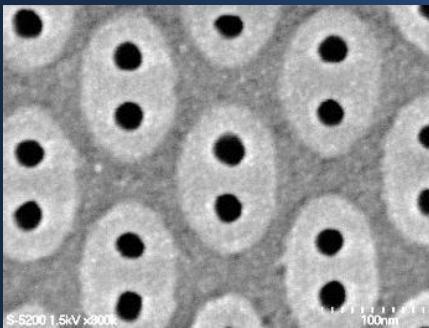
Ellipse Hole



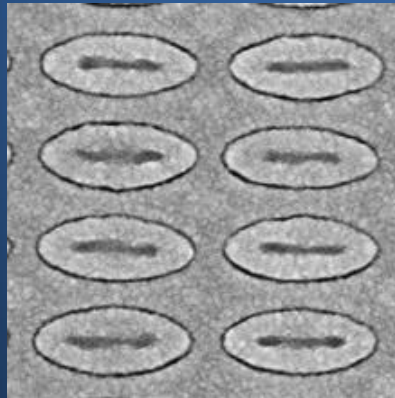
Trench



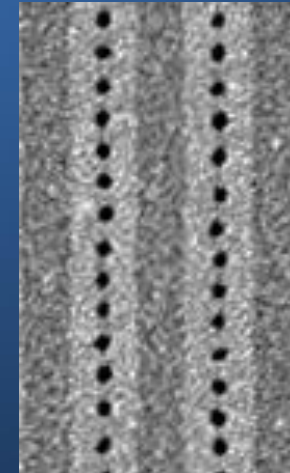
Hole Split (two 16nm holes)



Slit hole

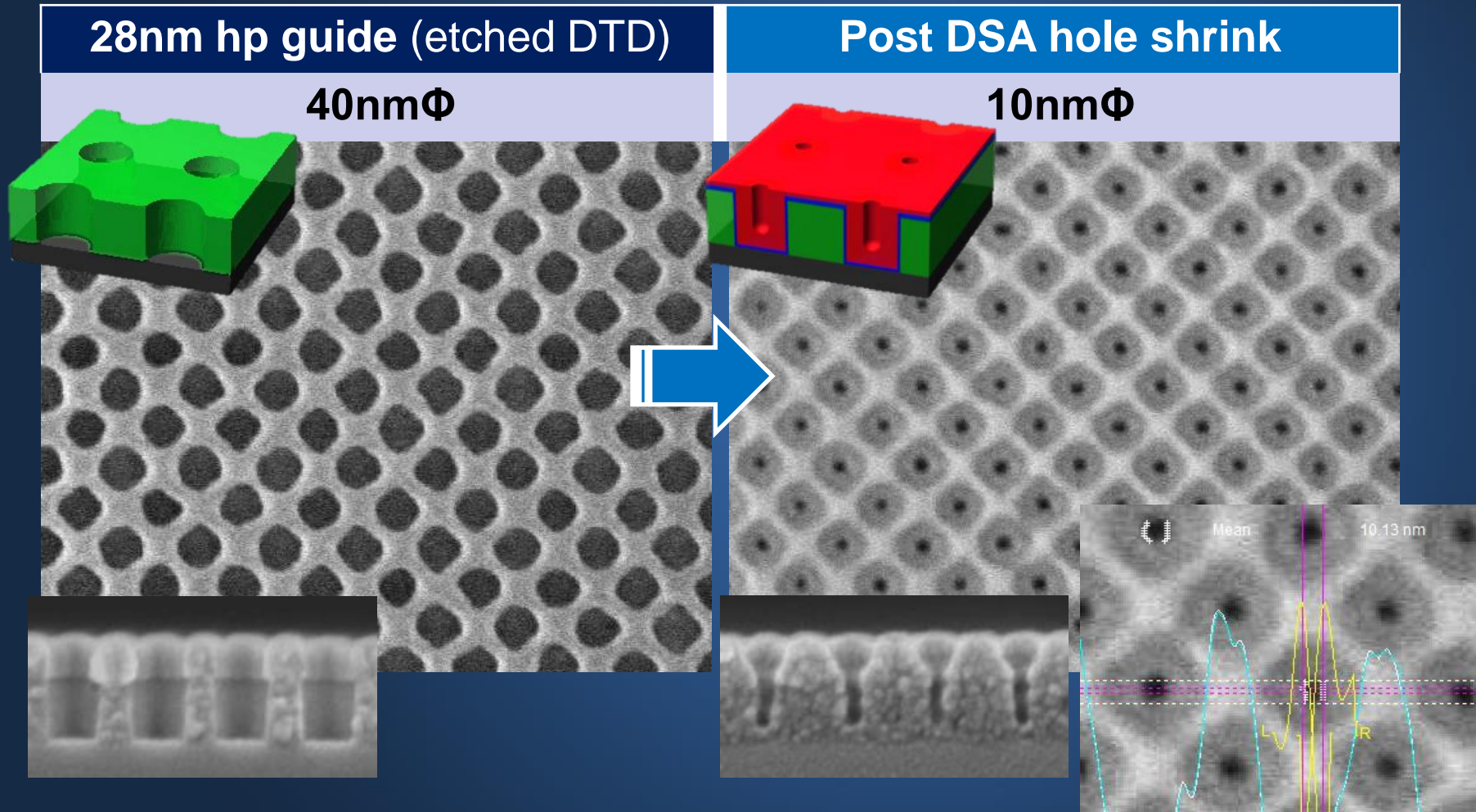


16nm 1:1 holes



B. Rath sack, et. al., "Advances in DSA integration and manufacturability at 300 mm", SPIE 8323-10 (2013)

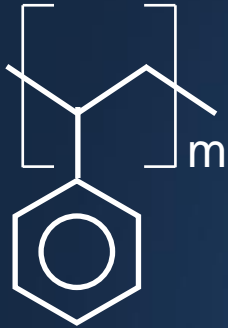
10 nm Holes (Dual Tone Develop + DSA)



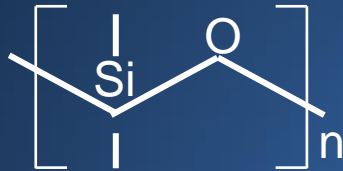
Kenichi Oyama , et. al., "Process variability of self-aligned multiple patterning", SPIE 8682-3 (2013)

PS-b-PDMS Material and Process

PS



PDMS



$$\chi_{PS/PDMS} \cong 0.2$$

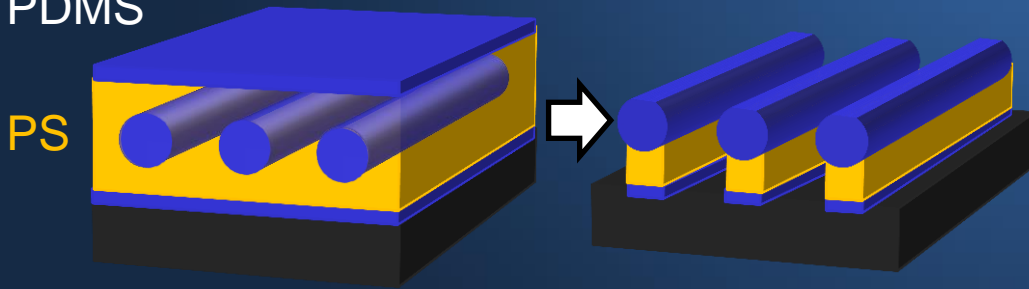
Dry Etching Step

Initial

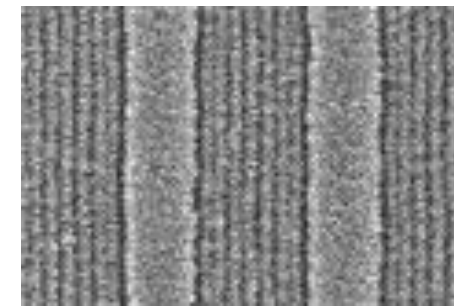
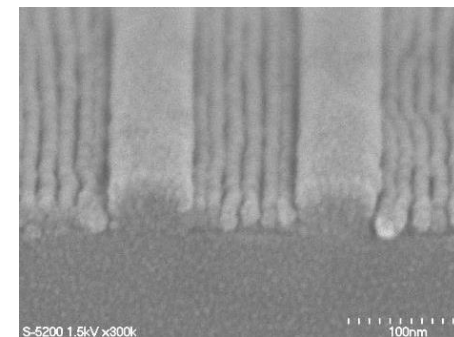
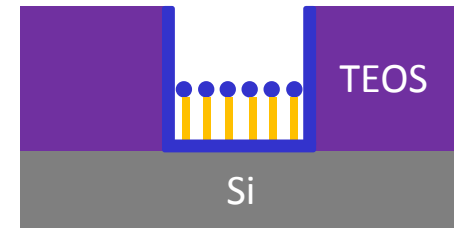
Etch

PDMS

PS



8 nm HP L/S
(Post Etch)



DSA Enabling Equipment

Directed self assembly integration is enabled by leveraging new materials and processes on advanced track, etch and cleaning system equipment

CLEAN TRACK™
LITHIUS Pro™ Z



Coat, Bake,
Develop

TACTRAS™



Etch

CELLESTA-i



Cleans



DSA Collaboration Ecosystem

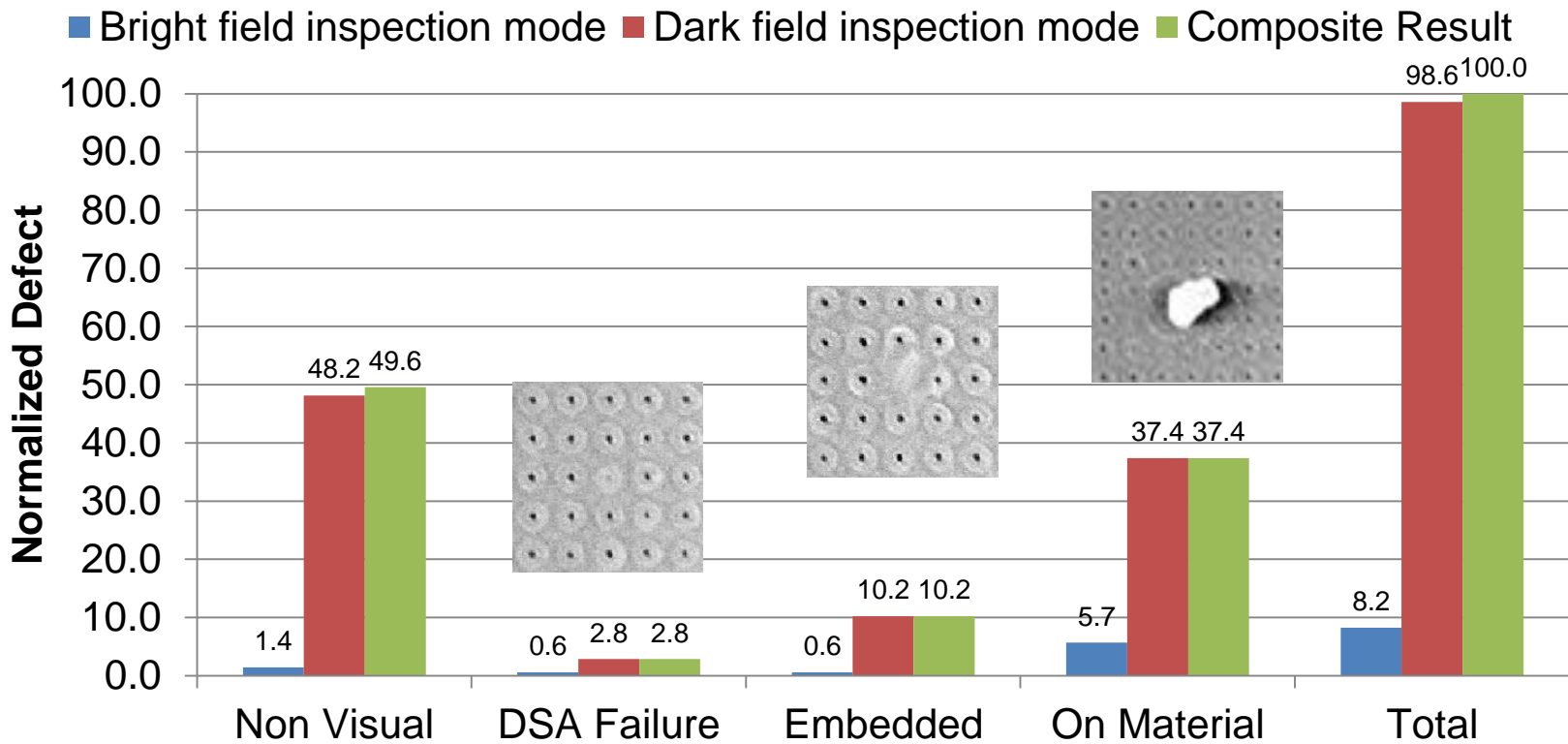
DSA Common Goal: Develop economically viable patterning solutions



Defect Inspection Analysis

(15 die 100% review)

- Embedded and on material defects are majority of the defect
- DSA failure defect accounts for 2.8% of the total number of defects



Harukawa, R. et. al., "DSA hole defectivity analysis using advanced optical inspection tool," SPIE 8681-76, (2013)

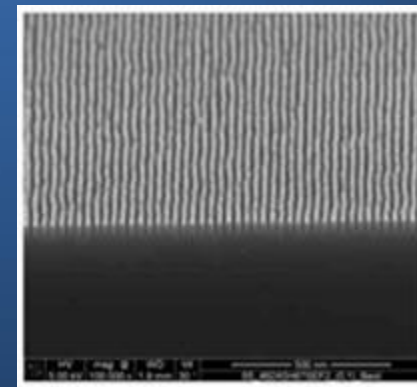
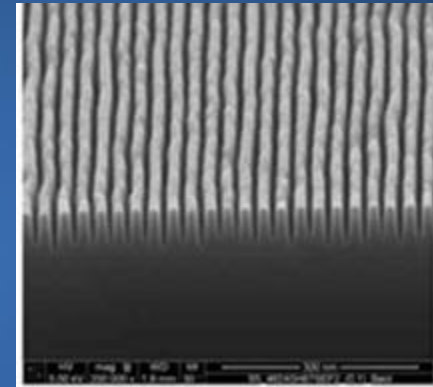
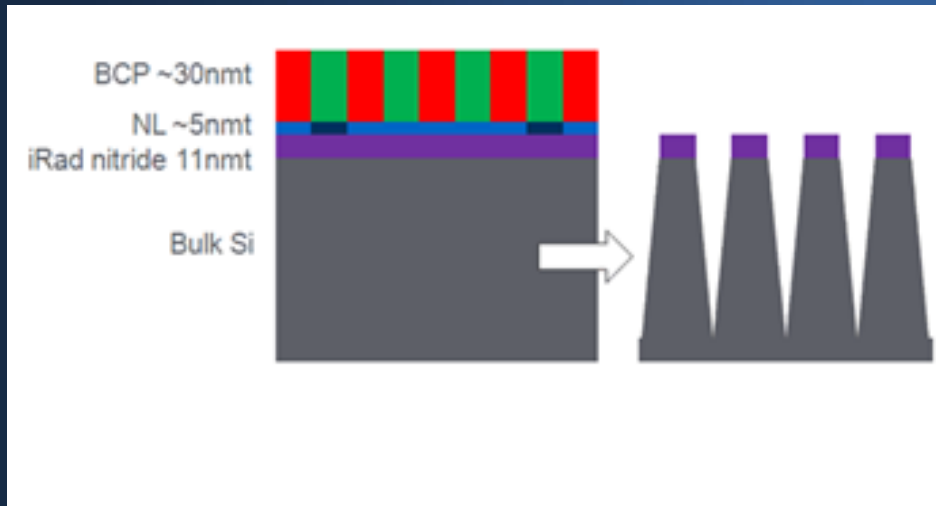
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Si Fin Device Integration

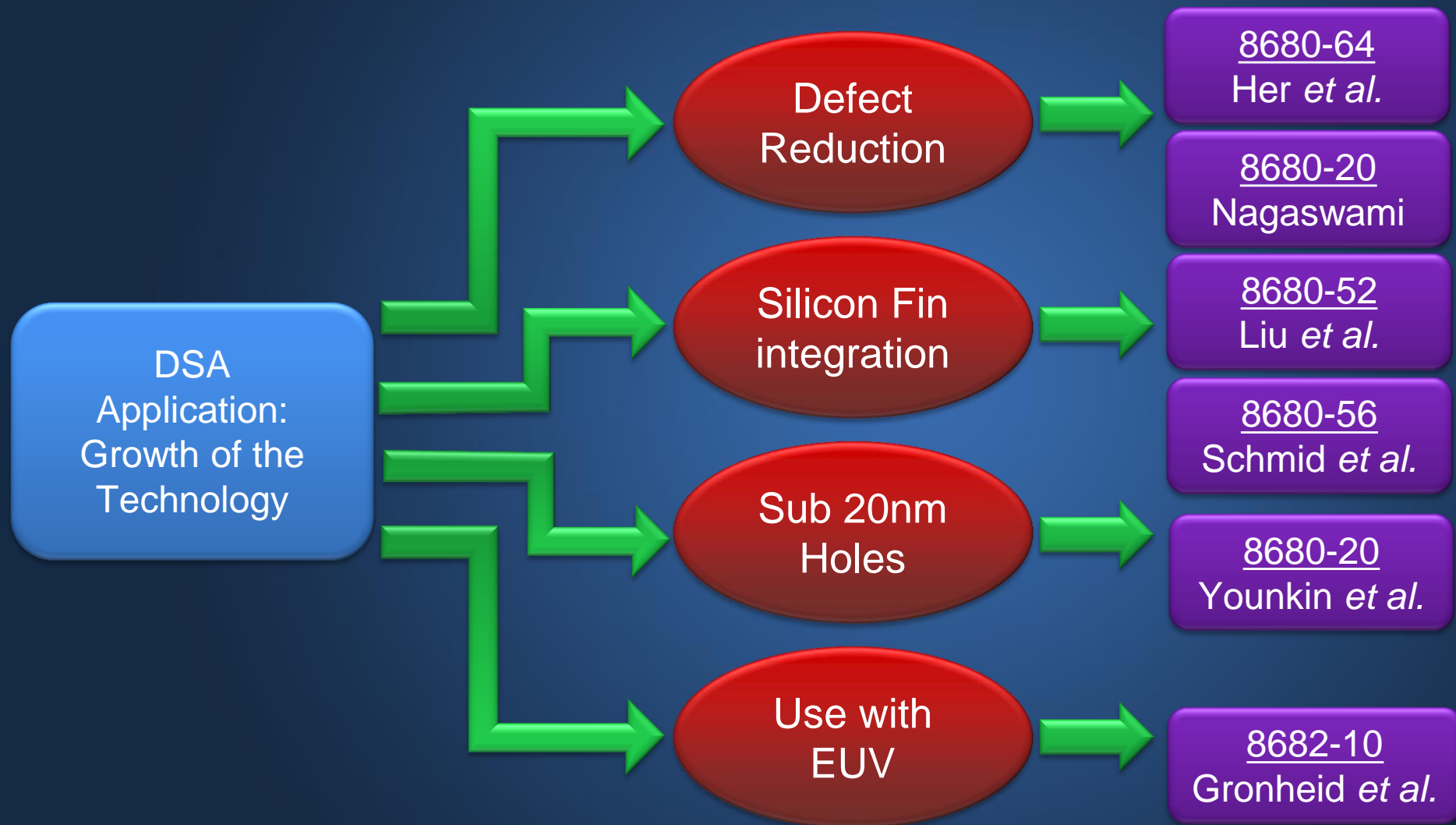
Through collaborative process development, DSA patterns have been etch transferred into device relevant substrate (silicon substrate)



Schmid, et. al., "Fabrication of 28nm pitch Si fins with DSA lithography, " SPIE 8680-51, (2013)

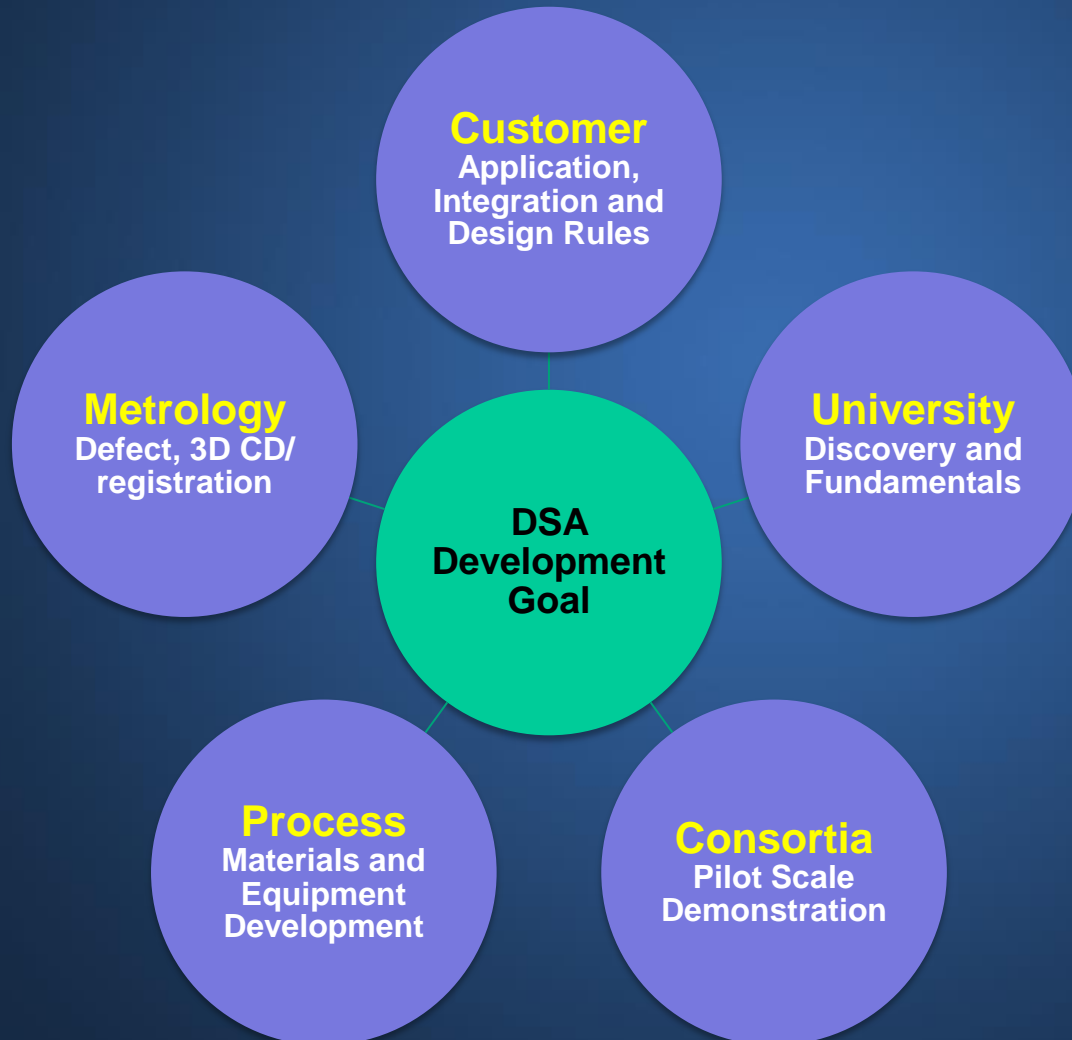


SPIE 2013 Collaboration Ecosystem



Summary

TEL is fostering a **DSA collaboration ecosystem** to address process development, defect reduction and device integration challenges



Acknowledgements

- IMEC (Dr. Roel Gronheid and team)
- University of Chicago (Prof. Paul Nealey, Prof. Juan De Pablo, Paulina Rincon)
- MIT (Prof. Caroline Ross and students)
- Material suppliers (AZ, DOW, TOK, JSR)
- Customer collaborations

THANK YOU FOR YOUR ATTENTION

